1 **WE CLAIM:**

1   1. A method for writing servo burst patterns for tracks on a rotating magnetic disk

2 medium, comprising:

3   track following along a first reference track, defined by previously written servo burst

4 patterns, using a servo control loop while writing servo burst patterns at a first target radial

5 location on the magnetic disk medium, the servo control loop having a closed-loop response and

6 including a two-dimensional digital state compensator having first and second inputs and first and

7 second outputs, the first input for receiving position error signals, the first output for generating

8 control signals for positioning a transducer head with respect to the selected track during track

9 following, the second output for generating track-following state variables, and the second input

10 for receiving combined track-following state variables;

11   processing and storing the track-following state variables generated at the second output

12 during the writing of the servo burst patterns at the first target radial location;

13   track following along a second reference track, defined by previously written servo burst

14 patterns, using the servo control loop while writing servo burst patterns at a second target radial

15 location on the magnetic disk medium;

16   processing and storing the track-following state variables generated at the second output

17 during the writing of the servo burst patterns at the second target radial location;

18   track following along a third reference track, defined by the previously written servo burst

19 patterns at the first and second radial target locations, using the servo control loop while writing

20 servo burst patterns at a third target radial location on the magnetic disk medium, wherein the

21 processed and stored track-following state variables generated at the second output during

22 writing of the servo burst patterns at the first and second target radial locations are combined, and

23 the combined track following state variables are applied to the second input during writing of the

24 servo burst patterns at the third target radial location.

1   2. A method for writing servo burst patterns as defined in claim 1, wherein the dimensions

2 of the two-dimensional digital state compensator are circumferential position and radial position.

1   3. A method for writing servo burst patterns as defined in claim 1, wherein the first

2   reference track is offset from the second reference track by more than one servo track, and the

3   third reference track is offset from the second reference track by at least one servo track.

1   4. A method for writing servo burst patterns as defined in claim 1, wherein each radial

2   location is offset from the corresponding reference track by at least one servo track.

1   5. A method for writing servo burst patterns as defined in claim 1, wherein processing the

2   track-following state variables generated at the second output comprises weighting and time

3   shifting the track-following state variables generated at the second output.

1   6. A method for writing servo burst patterns as defined in claim 1, wherein the

2   compensator is defined by the following equations:

$$\begin{bmatrix} \hat{x}_k(t+1) \\ \tilde{y}_{k+1}(t) \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix} + \begin{bmatrix} B_{11} \\ B_{21} \end{bmatrix} e_k(t)$$

3    $$u_k(t) = \begin{bmatrix} C_{11} & C_{12} \end{bmatrix} \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix}$$

$$\hat{y}_{k+1}(t) = \sum_{j=1}^{T} \alpha_j \tilde{y}_{k+1}(j)$$

4   where

5   k is the reference track number;

6   t is a servo wedge number or time;

7    $u_k(t)$ is the control signals for positioning the transducer head,

8    $x_k(t)$ is a state vector in a first dimension or time,

9    $\hat{y}_k(t)$ is the combined track-following state variables, in a second dimension or track

10   number,

11   $\tilde{y}_{k+1}(t)$ is the track-following state variables generated during writing of the servo burst

12   patterns,

13   $\hat{y}_{k+1}(t)$ is a weighted, time-shifted track-following state variable obtained from $\tilde{y}_{k+1}(t)$,

14   α_j are weight values,

15   T is the total number of servo wedges per track,

16    $e_k(t)$ is the position error signals (PES), and

17    $A_{11}, A_{12}, A_{21}, A_{22}, B_{11}, B_{21}, C_{11}, C_{12}$ are matrices of appropriate dimensions.

1   7. A method for writing servo burst patterns as defined in claim 1, wherein the

2   compensator is defined by the following equations:

3    $$\begin{bmatrix} \hat{x}_k(t+1) \\ \tilde{y}_{k+1}(t) \end{bmatrix} = \begin{bmatrix} A_g & 0 \\ C_g & 0 \end{bmatrix} \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix} + \begin{bmatrix} B_g \\ 0 \end{bmatrix} u_k(t) + K_e \left(e_k(t) - \hat{e}_k(t) \right)$$

4    $$\hat{e}_k(t) = \begin{bmatrix} -C_g & 1 \end{bmatrix} \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix}$$

5    $$u_k(t) = K_c \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix}$$

6    $$\hat{y}_{k+1}(t) = \sum_{j=1}^{T} \alpha_j \tilde{y}_{k+1}(j)$$

7   where

8   k is the reference track number;

9   t is a servo wedge number or time;

10    $e_k(t)$ is the position error signals (PES),

11    $\hat{e}_k(t)$ is an estimate of the PES,

12   (A_g, B_g, C_g) is a state space description of a head disk assembly,

13    $u_k(t)$ is the control signals for positioning the transducer head

14    $x_k(t)$ is a state vector in the first dimension or time,

15    $\hat{y}_k(t)$ is the combined track-following state variable, in a second dimension or track

16   number,

17    $\tilde{y}_{k+1}(t)$ is the track-following state variables generated during writing of the servo burst

18   patterns,

19    $\hat{y}_{k+1}(t)$ is a weighted, time-shifted track-following state variable obtained from $\tilde{y}_{k+1}(t)$,

20 T is the total number of servo wedges per track,

21 α_j are weight values,

22 K_e is an estimator gain, and

23 K_c is a compensator gain.

1 8. Apparatus for writing servo burst patterns for tracks on a rotating magnetic disk

2 medium, comprising:

3 means for track following along a first reference track, defined by previously written servo

4 burst patterns, using a servo control loop while writing servo burst patterns on a first target track

5 on the magnetic disk medium, the servo control loop having a closed-loop response and including

6 a two-dimensional digital state compensator having first and second inputs and first and second

7 outputs, the first input for receiving position error signals, the first output for generating control

8 signals for positioning a transducer head with respect to the selected track during track following,

9 the second output for generating track-following state variables, and the second input for

10 receiving combined track-following state variables;

11 means for processing and storing the track-following state variables generated at the

12 second output during the writing of the servo burst patterns at the first target radial location;

13 means for track following along a second reference track, defined by previously written

14 servo burst patterns, using the servo control loop while writing servo burst patterns at a second

15 target radial location on the magnetic disk medium;

16 means for processing and storing the track-following state variables generated at the

17 second output during the writing of the servo burst patterns on the second target radial location;

18 means for track following along a third reference track defined by the previously written

19 servo burst patterns at the first and second target radial locations using the servo control loop

20 while writing servo burst patterns at a third target radial location on the magnetic disk medium,

21 wherein the processed and stored track-following state variables generated at the second output

22 during writing of the servo burst pattern at the first and second target radial location are

23 combined, and the combined track following state variables are applied to the second input during

24 writing of the servo burst patterns at the third target radial location.

1   9. Apparatus for writing servo burst patterns as defined in claim 8, wherein the

2 dimensions of the two-dimensional digital state compensator are circumferential position and

3 radial position.

1   10. Apparatus for writing servo burst patterns as defined in claim 8, wherein the first

2 reference track is offset from the second reference track by more than one servo track, and the

3 third reference track is offset from the second reference track by at least one servo track.

1   11. Apparatus for writing servo burst patterns as defined in claim 8, wherein each radial

2 location is offset from the corresponding reference track by at least one servo track.

1   12. Apparatus for writing servo burst patterns as defined in claim 8, wherein:

2   the means for processing and storing the track-following state variables generated at the

3 second output during the writing of the servo burst patterns at the first target radial location

4 further weights and time shifts the track-following state variables generated at the second output;

5 and

6   the means for processing and storing the track-following state variables generated at the

7 second output during the writing of the servo burst patterns at the second target radial location

8 further weights and time shifts the track-following state variables generated at the second output.

1   13. Apparatus for writing servo burst patterns as defined in claim 8, wherein the

2 compensator is defined by the following equations:

$$\begin{bmatrix} \hat{x}_k(t+1) \\ \tilde{y}_{k+1}(t) \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix} + \begin{bmatrix} B_{11} \\ B_{21} \end{bmatrix} e_k(t)$$

3
$$u_k(t) = \begin{bmatrix} C_{11} & C_{12} \end{bmatrix} \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix}$$

$$\hat{y}_{k+1}(t) = \sum_{j=1}^{T} \alpha_j \tilde{y}_{k+1}(j)$$

4 where

5   k is the reference track number;

6   t is a servo wedge number or time;

7         $u_k(t)$ is the control signals for positioning the transducer head,

8         $x_k(t)$ is a state vector in a first dimension or time,

9         $\hat{y}_k(t)$ is the combined track-following state variables, in a second dimension or track

10 number,

11         $\tilde{y}_{k+1}(t)$ is the track-following state variables generated during writing of the servo burst

12 patterns,

13         $\hat{y}_{k+1}(t)$ is a weighted, time-shifted track-following state variable obtained from $\tilde{y}_{k+1}(t)$,

14   T is the total number of servo wedges per track,

15   α_j are weight values,

16         $e_k(t)$ is the positions error signals (PES), and

17         $A_{11}, A_{12}, A_{21}, A_{22}, B_{11}, B_{21}, C_{11}, C_{12}$ are matrices of appropriate dimensions.

1   14. Apparatus for writing servo burst patterns as defined in claim 8, wherein the

2 compensator is defined by the following equations:

3
$$\begin{bmatrix} \hat{x}_k(t+1) \\ \tilde{y}_{k+1}(t) \end{bmatrix} = \begin{bmatrix} A_g & 0 \\ C_g & 0 \end{bmatrix} \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix} + \begin{bmatrix} B_g \\ 0 \end{bmatrix} u_k(t) + K_e \left(e_k(t) - \hat{e}_k(t) \right)$$

4
$$\hat{e}_k(t) = \begin{bmatrix} -C_g & 1 \end{bmatrix} \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix}$$

5
$$u_k(t) = K_c \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix}$$

6
$$\hat{y}_{k+1}(t) = \sum_{j=1}^{T} \alpha_j \tilde{y}_{k+1}(j)$$

7 where

8   k is the reference track number;

9   t is a servo wedge number or time;

10         $e_k(t)$ is the position error signals (PES),

11         $\hat{e}_k(t)$ is an estimate of the PES,

12   (A_g, B_g, C_g) is a state space description of a head disk assembly,

13    $u_k(t)$ is the control signals for positioning the transducer head

14    $x_k(t)$ is a state vector in the first dimension or time,

15    $\hat{y}_k(t)$ is the combined track-following state variables, in a second dimension or track

16   number,

17    $\tilde{y}_{k+1}(t)$ is the track-following state variables generated during writing of the servo burst

18   patterns,

19    $\hat{y}_{k+1}(t)$ is a weighted, time-shifted track-following state variable obtained from $\tilde{y}_{k+1}(t)$,

20   T is the total number of servo wedges per track,

21   α_j are weight values,

22   K_e is an estimator gain, and

23   K_c is a compensator gain.

1   15. A method for defining tracks on a rotating magnetic disk medium, comprising:

2   track following along a reference track, defined by previously formed servo burst patterns

3   on the magnetic disk medium, using a servo control loop while forming servo burst patterns

4   defining a first target track, the servo control loop having a closed-loop response and including a

5   two-dimensional digital state compensator having first and second inputs and first and second

6   outputs, the first input for receiving position error signals, the first output for generating control

7   signals for positioning a transducer head with respect to the selected track during track following,

8   the second output for generating track-following state variables, and the second input for

9   receiving processed and stored track-following state variables;

10   processing and storing the track-following state variables generated at the second output

11   while forming the servo burst patterns defining the first target track;

12   track following along the first target track using the servo control loop while forming

13   servo burst patterns defining a second target track, wherein the processed and stored track-

14   following state variables generated at the second output while forming the servo burst patterns

15   defining the first target track are applied to the second input while forming the servo burst

16   patterns defining the second target track.

1   16. A method for defining tracks as defined in claim 15, wherein the dimensions of the

2   two-dimensional digital state compensator are circumferential position and radial position.

1   17. A method for defining tracks as defined in claim 15, wherein the first target track is

2   offset from the reference track by one servo track, and the second target track is offset from the

3   first target track by one servo track.

1   18. A method for defining tracks as defined in claim 15, wherein the first target track is

2   offset from the reference track by more than one servo track, and the second target track is offset

3   from the first target track by more than one servo track.

1   19. A method for writing servo burst patterns as defined in claim 15, wherein processing

2   the track-following state variables generated at the second output while forming the servo burst

3   patterns defining the first target radial track comprises weighting and time shifting the track-

4   following state variables generated at the second output.

1   20. A method for defining tracks as defined in claim 15, wherein the compensator is

2   defined by the following equations:

$$\begin{bmatrix} \hat{x}_k(t+1) \\ \tilde{y}_{k+1}(t) \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix} + \begin{bmatrix} B_{11} \\ B_{21} \end{bmatrix} e_k(t)$$

3
$$u_k(t) = \begin{bmatrix} C_{11} & C_{12} \end{bmatrix} \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix}$$

$$\hat{y}_{k+1}(t) = \sum_{j=1}^{T} \alpha_j \tilde{y}_{k+1}(j)$$

4   where

5   k is the track number;

6   t is a servo wedge number or time;

7        $u_k(t)$ is the control signals for positioning the transducer head,

8        $x_k(t)$ is a state vector in a first dimension or time,

9        $\hat{y}_k(t)$ is the stored track-following state variables, in a second dimension or track number,

10      $\tilde{y}_{k+1}(t)$ is the track-following state variables that are stored while forming the servo burst

11   patterns,

12      $\hat{y}_{k+1}(t)$ is a weighted, time-shifted track-following state variable obtained from $\tilde{y}_{k+1}(t)$,

13   T is the total number of servo wedges per track,

14   α_j are weight values,

15      $e_k(t)$ is the position error signals (PES), and

16      $A_{11}, A_{12}, A_{21}, A_{22}, B_{11}, B_{21,} C_{11}, C_{12}$ are matrices of appropriate dimensions.

1   21. A method for defining tracks as defined in claim 15, wherein the compensator is

2   defined by the following equations:

3
$$\begin{bmatrix} \hat{x}_k(t+1) \\ \tilde{y}_{k+1}(t) \end{bmatrix} = \begin{bmatrix} A_g & 0 \\ C_g & 0 \end{bmatrix} \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix} + \begin{bmatrix} B_g \\ 0 \end{bmatrix} u_k(t) + K_e \left(e_k(t) - \hat{e}_k(t) \right)$$

4
$$\hat{e}_k(t) = \begin{bmatrix} -C_g & 1 \end{bmatrix} \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix}$$

5
$$u_k(t) = K_c \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix}$$

6
$$\hat{y}_{k+1}(t) = \sum_{j=1}^{T} \alpha_j \tilde{y}_{k+1}(j)$$

7   where

8   k is the track number;

9   t is a servo wedge number or time;

10      $e_k(t)$ is the position error signals (PES),

11      $\hat{e}_k(t)$ is an estimate of the PES,

12   (A_g, B_g, C_g) is a state space description of a head disk assembly,

13      $u_k(t)$ is the control signals for positioning the transducer head

14      $x_k(t)$ is a state vector in the first dimension or time,

15      $\hat{y}_k(t)$ is the stored track-following state variable, in a second dimension or track number,

16      $\tilde{y}_{k+1}(t)$ is the track-following state variables that are stored while forming the servo burst

17   patterns,

18     $\hat{y}_{k+1}(t)$ is a weighted, time-shifted track-following state variable obtained from $\tilde{y}_{k+1}(t)$,

19   T is the total number of servo wedges per track,

20   α_j are weight values,

21   K_e is an estimator gain, and

22   K_c is a compensator gain.

1   22. Apparatus for defining tracks on a rotating magnetic disk medium, comprising:

2   means for track following along a reference track, defined by previously formed servo

3 burst patterns on the magnetic disk medium, using a servo control loop while forming servo burst

4 patterns defining a first target track, the servo control loop having a closed-loop response and

5 including a two-dimensional digital state compensator having first and second inputs and first and

6 second outputs, the first input for receiving position error signals, the first output for generating

7 control signals for positioning a transducer head with respect to the selected track during track

8 following, the second output for generating track-following state variables, and the second input

9 for receiving processed and stored track-following state variables;

10   means for processing and storing the track-following state variables generated at the

11 second output while forming the servo burst patterns defining the first target track;

12   means for track following along the first target track using the servo control loop while

13 forming servo burst patterns defining a second target track, wherein the processed and stored

14 track-following state variables generated at the second output while forming the servo burst

15 patterns defining the first target track are applied to the second input while forming the servo

16 burst patterns the second target track.

1   23. Apparatus for defining tracks as defined in claim 22, wherein the dimensions of the

2 two-dimensional digital state compensator are circumferential position and radial position.

1   24. Apparatus for defining tracks as defined in claim 22, wherein the first target track is

2 offset from the reference track by one servo track, and the second target track is offset from the

3   first target track by one servo track.

1   25. Apparatus for defining tracks as defined in claim 22, wherein the first target track is

2   offset from the reference track by more than one servo track, and the second target track is offset

3   from the first target track by more than one servo track.

1   26. Apparatus for defining tracks as defined in claim 22, wherein the means for

2   processing and storing the track-following state variables generated at the second output while

3   forming the servo burst patterns defining the first target track further weights and time shifts the

4   track-following state variables generated at the second output.

1   27. Apparatus for defining tracks as defined in claim 22, wherein the compensator is

2   defined by the following equations:

$$\begin{bmatrix} \hat{x}_k(t+1) \\ \tilde{y}_{k+1}(t) \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix} + \begin{bmatrix} B_{11} \\ B_{21} \end{bmatrix} e_k(t)$$

3
$$u_k(t) = \begin{bmatrix} C_{11} & C_{12} \end{bmatrix} \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix}$$

$$\hat{y}_{k+1}(t) = \sum_{j=1}^{T} \alpha_j \tilde{y}_{k+1}(j)$$

4   where

5   k is the track number;

6   t is a servo wedge number or time;

7        $u_k(t)$ is the control signals for positioning the transducer head,

8        $x_k(t)$ is a state vector in a first dimension or time,

9        $\hat{y}_k(t)$ is the stored track-following state variables, in a second dimension or track number,

10       $\tilde{y}_{k+1}(t)$ is the track-following state variables that are stored while generating the servo

11   burst patterns,

12       $\hat{y}_{k+1}(t)$ is a weighted, time-shifted track-following state variable obtained from $\tilde{y}_{k+1}(t)$,

13   T is the total number of servo wedges per track,

14   α_j are weight values,

15      $e_k(t)$ is the position error signals (PES), and

16      $A_{11}, A_{12}, A_{21}, A_{22}, B_{11}, B_{21}, C_{11}, C_{12}$ are matrices of appropriate dimensions.

1   28. Apparatus for defining tracks as defined in claim 22, wherein the compensator is

2 defined by the following equations:

3
$$\begin{bmatrix} \hat{x}_k(t+1) \\ \tilde{y}_{k+1}(t) \end{bmatrix} = \begin{bmatrix} A_g & 0 \\ C_g & 0 \end{bmatrix} \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix} + \begin{bmatrix} B_g \\ 0 \end{bmatrix} u_k(t) + K_e \left(e_k(t) - \hat{e}_k(t) \right)$$

4
$$\hat{e}_k(t) = \begin{bmatrix} -C_g & 1 \end{bmatrix} \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix}$$

5
$$u_k(t) = K_c \begin{bmatrix} \hat{x}_k(t) \\ \hat{y}_k(t) \end{bmatrix}$$

6
$$\hat{y}_{k+1}(t) = \sum_{j=1}^{T} \alpha_j \tilde{y}_{k+1}(j)$$

7 where

8   k is the track number;

9   t is a servo wedge number or time;

10      $e_k(t)$ is the position error signals (PES),

11      $\hat{e}_k(t)$ is an estimate of the PES,

12   (A_g, B_g, C_g) is a state space description of a head disk assembly,

13      $u_k(t)$ is the control signals for positioning the transducer head

14      $x_k(t)$ is a state vector in the first dimension or time,

15      $\hat{y}_k(t)$ is the stored track-following state variable, in a second dimension or time,

16      $\tilde{y}_{k+1}(t)$ is the track-following state variables that are stored while forming the servo burst

17 patterns,

18      $\hat{y}_{k+1}(t)$ is a weighted, time-shifted track-following state variable obtained from $\tilde{y}_{k+1}(t)$,

19   T is the total number of servo wedges per track,

20   α_j are weight values,

21   K_e is an estimator gain, and

22   K_c is a compensator gain.